

4.0 PARTICLE FORMATION AND INTERACTION

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4.1 Introduction

A wide variety of experiments that involve the physics of small particles (μm to cm in size) of planetary significance can be conducted on the Space Station. Processes of interest include nucleation and condensation of particles from a gas, aggregation of small particles into larger ones, and low velocity collisions of particles. All of these processes could be investigated with a general-purpose facility on the Space Station for study of the physics of small particles. The microgravity environment of the Space Station would be necessary to perform many experiments, as they generally require that particles be suspended for periods substantially longer than are practical at 1-g. Only experiments relevant to planetary processes will be discussed in detail here, but it is important to stress that a particle research facility will be useful to a wide variety of scientific disciplines, and can be used to address many scientific problems. We will also discuss briefly some experiments that would not utilize such a facility. More detailed descriptions of some specific experiments are presented in the workshop abstracts.

4.2 Background and Scientific Rationale

Some of the most fundamental processes involved in the origin and evolution of the Solar System concern the condensation of solid matter from a gas, the aggregation of small particles to form larger particles, and the collisional interaction of particles over a range of sizes. Understanding particle condensation is critical to understanding the earliest stages of solar system formation. Classical nucleation theory is inadequate to predict the condensation of circumsolar grains from the early solar nebula. Experiments have been performed in terrestrial laboratories to duplicate the nucleation and condensation of planetary particles from the solar nebula, but such experiments suffer from convective instabilities induced in the gas from which the condensation takes place. In a microgravity environment, it will be possible to conduct condensation experiments with more quantitative accuracy, and to extend experiments to much more refractory materials. Experiments extended to low temperature condensation will also be able to investigate formation of icy grains that were involved in accretion of the outer planets, their satellites, and comets.

Once grains formed by condensation in the early solar nebula, they underwent aggregation into planetesimals. This process is poorly understood, particularly in the scenario where significant amounts of gas are still present. Particle aggregation is also an important part of any process that injects large amounts of comminuted material into a planetary atmosphere. Three such processes are dust storms, explosive volcanic eruptions, and large impact events. For example, it has been hypothesized that a large impact could have caused substantial atmospheric dust loading on Earth and subsequent faunal extinctions. Such hypotheses are dependent on the efficacy of dust aggregation and the rate at which particle aggregates settle from the atmosphere. Aggregation rates also play a crucial role in calculations of "nuclear winter" scenarios, and control the lifetime of some volcanic plumes and large dust storms. Some laboratory experiments suggest that aggregation, at least under some conditions, is surprisingly effective, but all aggregation experiments are severely restricted in duration by rapid settling in a 1-g gravitational field. The microgravity environment on the Space Station will allow the process of particle aggregation to be studied in great detail under a wide range of conditions. Specific parameters that need investigation include aggregation rates, the size distribution of aggregates, the dependence of aggregation efficacy on material properties, etc.

Immediately after the first stages of particle aggregation in the solar nebula, planetesimal formation probably involved collision of particles at relative velocities of a few m/sec or less. The detailed dynamics of such collisions are poorly understood, including particularly the nature of the conditions necessary for particles to adhere together after a collision. Factors that affect collision dynamics probably include particle composition, relative sizes, spin, and ambient gas pressure. The effects of all these factors are poorly known. Low velocity particle collisions also take place in planetary ring systems. Collisions result in an effective viscosity for the rings, and development of diffusional instabilities that are manifested as intricate small-scale structures. In this case the important parameter to understand is the coefficient of restitution, which describes the inelasticity of collisions. Attempts have been made to study low velocity particle collisions by suspending particles from pendula, but such experiments suffer severely from the restriction of particle motions to two dimensions. Full three-dimensional interactions, including interaction of more than two particles, can be conducted in a microgravity environment.

4.3 Hardware Concept

The high cost of experimentation on the Space Station provides a strong motivation to develop orbital laboratory facilities that will be capable of addressing as wide a range of

problems as possible, rather than highly specialized facilities applicable to only one narrow problem. In principle, all of the investigations outlined above could be conducted in a chamber in which particle formation and interaction could be induced and observed. One possible concept for such a facility will be described below. A critical task to be carried out in the near term is determination of which investigations can be conducted in a general particle research facility, and which require more specialized facilities. The general objective will be to design a facility that is as flexible as possible, admitting as many high-priority investigations as are feasible without compromising the science. The design discussed here is very preliminary, and will be subjected to substantial review, refinement, and revision.

The basic facility is envisioned as residing in a glove box in one of the Space Station laboratory modules. It is felt that the glove box approach is necessary to ensure against contamination of the module interior with particles. The glove box must be at least the size of a double rack (38 inches wide) in order to accommodate the necessary equipment. It should be as voluminous as possible, and include internal power outlets and attachment to a thermal control system. The experimental chamber itself would be mounted inside the glove box. It should also be as voluminous as possible while allowing space for external attachments within the confines of the glove box; for a double rack glove box, an experiment chamber 24 inches on a side might be appropriate. All faces should be readily accessible to an experimenter outside the glove box, and the positioning of the chamber within the glove box should be adjustable. The chamber should be pressure tight, and at least one face should be completely removable. Each face should be equipped with a general-purpose port to which investigators may attach equipment. Some standard pieces of equipment should be provided as part of the facility. These might include illumination sources, still or motion picture cameras, laser nephelometers, or photometers. In the case where an investigator could not build a piece of equipment that would be compatible with a general-purpose port, the investigator could provide an entire removable face of the chamber to which his or her equipment would be attached. In the extreme case where the chamber itself is unsuitable for an investigator, it should be possible for the investigator to remove the chamber and insert a specialized one that meets his or her requirements.

The amount of crew interaction that will be required by these experiments will of course vary from one experiment to the next. In general, however, it is expected that most will require the close attention of at least one individual, either the investigator or a trained crew member. A particle research facility shares the need to effectively handle significant quantities of small particles with a number of other possible Space Station experiments, including impact experiments and a wind tunnel. This common need suggests that a

standardized procedure for transporting and handling particles should be established. Equipment developed for particle transportation, handling, and storage should be as general as possible.

Several of the particle-related experiments described in the abstracts could not be accomplished in a facility within the Space Station, but could be conducted outside the Station. These include experiments to collect micrometeorites, and experiments to study the orbit properties of colliding, co-orbiting bodies. Facilities for the conduct of these experiments might be constructed outside the Space Station, or could perhaps be accommodated on free-flying spacecraft.

4.4 Recommendations

A particle research facility should be developed for the Space Station and maintained as a national facility for research involving the physics and chemistry of small particles in microgravity.

A multi-disciplinary workshop was conducted to define clearly the scientific rationale for the particle research facility, establish the desired capabilities of the facility, and establish a strawman design. This workshop was held at Ames Research Center on August 22-24, 1985. A major focus of the workshop was to establish the degree to which widely differing investigations can share the same facility, and how many specialized chambers are actually necessary.

An effort should be made to obtain funding for the facility at a level sufficient for completion at the time the Space Station reaches its Initial Operating Capability (IOC). Potential funding sources include the Astrophysics, Planetary Science, and Life Sciences programs in the Office of Space Science and Applications, as well as the Space Station Office itself.

The Space Station should be constructed in a manner that allows the development of large particle collection and interaction experiments outside the main Station structure.